Award Number: DAMD17-03-2-0026


TITLE: Prediction of Body Surface Area Based on 3-Dimensional Laser Scans


PRINCIPAL INVESTIGATOR: James A. Hodgdon, Ph.D.


CONTRACTING ORGANIZATION: T.R.U.E. Research Foundation
San Antonio, TX 78217


REPORT DATE: March 2005


TYPE OF REPORT: Final


PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012


DISTRIBUTION STATEMENT: Approved for Public Release;
Distribution Unlimited


The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.


# 20060503246

# REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

| 1. REPORT DATE (DD-MM-YYYY)<br>01-09-2005 | 2. REPORT TYPE<br>Final | 3. DATES COVERED (From - To)<br>1 Mar 2003 – 28 Feb 2005 |
|---|---|---|

**4. TITLE AND SUBTITLE**
Prediction of Body Surface Area Based on 3-Dimensional Laser Scans

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**
DAMD17-03-2-0026

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
James A. Hodgdon, Ph.D.

E-mail: hodgdon@nhrc.navy.mil

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

T.R.U.E. Research Foundation
San Antonio, TX 78217

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for Public Release; Distribution Unlimited

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

Treatment of many military-relevant diseases depends on knowledge of body surface area (BSA). BSA is typically estimated using predictive formulae that were developed using a variety of measurement techniques. More recently, techniques to use the 3-D laser scanner to provide precise measurement of BSA have been developed. The objectives of this study are to accomplish the following: (1) collect measurements of BSA from whole-body laser scans, (2) determine the accuracy of currently used BSA estimation formulae based on stature and weight, (3) determine the impact of additional body dimensions on the accuracy of BSA estimation, (4) determine the reliability of BSA prediction from laser scans, (5) determine differences between two scanner types, and (6) develop new models that include use of body circumferences and segment lengths as predictor variables. Objectives (1) through (4) have been completed. The Vitronic Viro scanner provides a reliable method of measuring BSA. BSA prediction from currently used equations provides a satisfactory value. Stature and weight are sufficient to predict BSA accurately. Predictions of BSA from stature and weight do not have to be adjusted for gender. Addition or substitution of other anthropometric variables does not appear to improve predictive accuracy.

**15. SUBJECT TERMS**
Whole body scans, 3-dimensional laser scanning, body surface area, anthropometry, girths, limb lengths.

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON<br>USAMRMC |
|---|---|---|---|---|---|
| a. REPORT<br>U | b. ABSTRACT<br>U | c. THIS PAGE<br>U | UU | 10 | 19b. TELEPHONE NUMBER (include area code) |

**TABLE OF CONTENTS:**

# Prediction Of Body Surface Area Based On 3-Dimensional Laser Scans.

James A. Hodgdon[1], Ph.D.; Martine Brandsma[2], M.S.;
Hein Daanen[2], Ph.D. and Linda Hervig[1], M.S.

[1]Naval Health Research Center
San Diego, CA 92152, USA

[2]TNO Human Factors Research Institute
3769 ZG Soesterberg, The Netherlands

**INTRODUCTION:**

Treatment of many military-relevant diseases depends on knowledge of body surface area (BSA). In the chemical industry, models are used to estimate the toxicity of materials that penetrate the skin. The exposed skin area is crucial for the accuracy of the model predictions. Such calculations are important in the determination of the effects of exposure to chemical agents. In chemotherapy, BSA is needed to calculate drug dosage. In thermal physiology, BSA values are necessary to calculate heat transfer. BSA is critical to the functioning of heat response models, and thus prediction of risk of heat illness. Serious over- or underestimation may occur when the surface area is incorrectly determined. For military clothing applications, surface area is important for design and manufacture of clothing that fits comfortably and allows adequate air circulation for proper temperature maintenance. Finally, determination of surface area in burn victims is essential to estimate the clinical outcome. Accuracy of body surface area measurements in all of these areas is very important.

BSA is typically estimated using predictive formulae that were developed using a variety of measurement techniques. These techniques range from applying paper to the surface of the body and measuring the contact area to measuring the reflectance area of the skin with bright light. More recently, a new technology was developed which allows precise measurement of BSA, namely the 3-D laser scanner. The Netherlands Organization for Applied Scientific Research (TNO) currently has a Vitronic Viro 3D-pro scanner. With this scanner, TNO is participating as the European member in the Civilian American and European Surface Anthropometry Resource (CAESAR) project begun by the U.S. Air Force. The objective of the CAESAR program is to build a new database of descriptive measurements of human dimensions. The database will be used to improve the fit of military and civilian clothing and the design of military and commercial vehicles (including aircraft) and military weapon systems to accommodate the human form.

This study will use laser scans to measure the BSA of human subjects and to determine whether or not formulas for the prediction of body surface area need to be revised. Better calculation of BSA will improve the treatment of diseases and models of chemical and thermal exposure.

The objectives of this study are to accomplish the following: (1) collect measurements of BSA from whole-body laser scans, (2) determine the accuracy of currently used BSA estimation formulae based on stature and weight, (3) determine the impact of additional body dimensions on the accuracy of BSA estimation, (4) determine the reliability of BSA prediction from laser scans, (5) determine differences between two scanner types, and (6) develop new models that include

1

use of body circumferences and segment lengths as predictor variables.

The study is a comparative study. Subjects to be measured on the Vitronic Viro scanner will be stratified into five ranges according to their estimated BSA calculated using the Dubois and Dubois (1916) formula. Anthropometric measurements will be made on these subjects, and a 3-dimensional body scan will be obtained. Four subjects in each BSA range will be randomly selected and asked to return later in the day for a second scan to provide the basis for a system reliability determination. Extant data from CEASAR database will be used to compare two different scanner types.

Subjects to be scanned with the Vitronic Viro scanner in this study will be fifty (approximately 25 men and 25 women) healthy Dutch citizens 18 – 55 years of age. The subjects will be selected to provide equal representation within BSA quintiles based on estimations from the application of an equation that uses height and weight to a U.S. Navy population sample (unpublished data, N = 86,641). Quintiles for BSA (in $m^2$) are BSA < 1.81, $1.81 \leq BSA < 1.92$, $1.92 \leq BSA < 2.01$, $2.01 \leq BSA < 2.12$, and $BSA \geq 2.12$. Because men and women differ in body surface area on average, it is not anticipated that the number of men and number of women will be equal in each quintile. Particular attention will be paid to choosing subjects representing a range of segment proportionalities (e.g. leg length/stature). It is intended that the results of this study generalize to U.S. military populations. The sample size is based on data from a pilot study (Tan, Brandsma & Daanen; 2001) and a power of 0.80 and P < 0.05.

Existing scans for 32 additional subjects will be analyzed as follows:

(1) An extant set of 12 subjects who were measured using both a Vitronic Viro and Cyberware scanner will have BSA determined from scans recorded on each machine. These BSA values will be analyzed to compute an inter-machine reliability.

(2) Scan data for ten male and ten female subjects will be selected from the U.S. CAESAR database and processed to determine BSA. A comparable set based on stature, weight, ethnicity, and limb length proportion will be selected from the current study database. The United States (US) and Dutch (NL) data will be compared to determine whether or not the choice of NL subjects will affect the accuracy of models applied to US personnel.

**BODY:**

Objectives (1) through (4) have been completed and the findings relative to those objectives are provided below. The analysis of the scans needed to complete objectives (5) and (6) is almost complete.

**Study 1, objectives (1) through (4).**

1. Methods

Fifty-two Dutch participants of military age (26 male, 26 female) underwent scanning with the Vitronic Viro scanner at TNO. Twenty-one participants returned for a second scan later in the same day. The 3-dimensional point cloud files generated by the scanner were analyzed using PolyWorks (InnovMetric, Quebec City, Quebec, CANADA). The software links adjacent points using triangles, the area of these triangles can be summed to provide a measurement of the surface area of the shape (in this case, the body image). The software also provides tools for filling in areas that are not "seen" in the laser scan, and for editing triangles that are not part of

2

the body surface area representation. The parts of the scans representing the feet and hands were analyzed separately to make object handling easier. The surface areas of the hands and feet were added to that of the major body image to arrive at the total area.

In addition, the following anthropometric variables were measured for possible inclusion in models to predict BSA: body mass, stature, sitting height, arm length, inseam length, hand length and breadth, foot length, breadth and circumference, neck, arm, forearm, shoulder, chest, abdominal, waist, hip, mid-thigh and calf girths, and biacromial diameter. All anthropometry measurements were made twice. Means of the duplicate measurements were used for analysis.

Estimates of BSA from stature and weight were calculated from the equations of Boyd (1935); Dubois and Dubois (1916); Haycock, Schwartz & Wisotsky (1978); Mitchell et al (1971); Moesteller (1987); and Tikuisis (2001). These equations are provided in Appendix A.

Strength of association among measures was determined using Pearson correlation coefficients. Differences among estimates of BSA and between BSA estimates and BSA determined from the laser scans were compared using repeated-measures analysis of variance with post-hoc pairs analysis using t-tests for correlated means. Significance was accepted for $P \leq 0.05$. Analyses were carried out using SPSS for windows, v11.5 (SPSS Inc., Chicago, IL).

## 2. Results

### a. Subjects

Subjects were recruited from the Dutch population in the area surrounding Soesterberg. The physical characteristics of the subjects are provided in Table 1. Men differed from women in all characteristics except age.

**Table 1.** Participant Characteristics[1]

|  | Males (N = 26) | Females (N = 26) | Total (N = 52) |
|---|---|---|---|
| Age (y) | 26.1 (7.7) | 23.9 (5.9) | 25.0 (6.9) |
| Stature (cm) | 182.8 (7.2) | 169.0 (5.6) | 175.9 (9.5) |
| Mass (kg) | 78.4 (12.6) | 62.4 (7.5) | 70.4 (13.0) |
| Body Fat Content (%)[2] | 16.0 (4.9) | 27.1 (3.7) | 21.6 (7.1) |
| BSA (m²) | 1.94 (0.18) | 1.68 (0.13) | 1.82 (0.20) |

[1] Values shown are means (1 SD)
[2] Estimated from circumferences and stature after Hodgdon & Friedl (1999)

### b. Reliability

Two laser scans were obtained for 21 subjects. Reliability of the BSA values computed from the scans was determined. The single-measure intraclass correlation for BSA determined from the laser scans was 0.9968. The value for alpha was 0.9986.

Stature and weight were measured twice at the time of each scan. The single-measure intraclass correlation for stature with four measures (twice for each of two scan sessions) was 0.9992 (alpha = 0.9998), and for two measures (all participants for their first scan) was also 0.9992 (alpha = 0.9996). For weight, the single-measure intraclass correlation was 0.9998

when 4 weights were taken (alpha = 1.0), and 0.9997 (alpha = 0.9999) for pairs of measures taken at the time of the first (sometimes only) scan. It is clear that all the measures used in this analysis were obtained in a highly reliable manner.

c. Comparisons of BSA values

Table 2 provides the correlations among the estimates of BSA from currently used equations and with BSA from the laser scans. As can be seen, the correlations are close to 1 indicating a very large degree of association among the variables. The average variance accounted for is 98.5% between laser-scan BSA values and those predicted from stature and weight. The average variance accounted for in the intercorrelations among the predicted values is 99.6%.

**Table 2.** Correlations among the BSA measures

|            | Laser Scan | Dubois | Boyd  | Haycock | Mitchell | Moesteller |
|------------|-----------|--------|-------|---------|----------|------------|
| Dubois     | 0.993     |        |       |         |          |            |
| Boyd       | 0.991     | 0.994  |       |         |          |            |
| Haycock    | 0.992     | 0.992  | 1.000 |         |          |            |
| Mitchell   | 0.993     | 1.000  | 0.994 | 0.996   |          |            |
| Moesteller | 0.993     | 0.998  | 0.999 | 1.000   | 0.998    |            |
| Tikuisis   | 0.992     | 0.992  | 0.999 | 1.000   | 0.997    | 1.000      |

While strongly associated with one another, the estimates of BSA were found to differ significantly among themselves (repeated measures ANOVA, $F_{2,104}$ = 674.85, $P$ < 0.001). Significant differences based on *post hoc* analysis of the BSA values are indicated in Table 3.

**Table 3.** Differences[1] among BSA values

|                                  | Laser Scan | Moesteller | Haycock | Boyd    | Dubois  | Mitchell | Tikuisis |
|----------------------------------|-----------|------------|---------|---------|---------|----------|----------|
| Mean BSA (cm$^2$)                | 18153.2   | 18528.7    | 18539.6 | 18558.4 | 18588.2 | 17566.1  | 17362.2  |
| Mean difference[2] (cm$^2$)      |           | 375.46     | 386.46  | 405.26  | 435.04  | -587.10  | -790.96  |
| Mean difference[3] (%)           |           | 2.1%       | 2.1%    | 2.2%    | 2.4%    | -3.2%    | -4.4%    |

[1] Lines are drawn below values that do not differ significantly ($P$ > 0.05).
[2] Differences are between predicted and laser scan values
[3] Predicted – laser scan difference as a percent of the mean laser scan value

As can be seen in Table 3, the laser scan differs significantly from the predicted values generated by each of the equations tested. However, it should be noted that the discrepancies are not great in value (within 2.1 – 4.4 % of the laser scan values). It does not appear that any of the differences between the laser-scan BSA values and predicted BSA values are of practical significance.

### d. Gender effects

The influence of gender on prediction of BSA using these extant equations was evaluated by testing for parallelism of regression lines based on gender between predicted values and those derived from the laser scans. For each predictive equation, significant effects of gender (denoting a difference in regression intercept) and the gender by predicted value interaction (denoting a difference in regression slope) was found. However, the finding of significant differences appears to be largely an effect of the large correlation between predicted and laser scan values (see Table 2). In no case did the percentage of variance accounted for by the sum of the intercept and slope differences exceed 0.5% (mean = 0.35%, range = 0.27 – 0.44%). It does not appear meaningful to adjust the predicted values for gender. (It should be noted that the predictions of Tikuisis and colleagues already utilize separate equations for men and women.)

### e. New predictive equations

Based on the discussion above, it does not appear that new equations are needed for the prediction of BSA. However, we did pursue their development from these data as a way of summarizing our results. We developed equations using a linear model of stature and weight, and in the most commonly occurring form of BSA = a x stature$^b$ x weight$^c$, where a, b, and c are constants.

The best linear equation was:
$$BSA(cm^2) = 67.126 \times height(cm) + 111.47 \times weight(kg) - 1526.4$$
$R^2 = 0.985$, std err of meas. = 258.8 cm$^2$

The best nonlinear equation of the common form was:
$$BSA(cm^2) = 115.823 \times height(cm)^{.612} \times weight(kg)^{.445}$$
$R^2 = 0.988$, std err of meas. = 228.2 cm$^2$

As can be seen, the variance accounted for increases by only 0.3% by using the nonlinear form.

Stature and weight appear to be the only variables needed for the accurate prediction of BSA. We attempted to include other anthropometric variables into the prediction of BSA, and in no case did we find an anthropometric variable that more highly correlated with BSA than stature or weight, either upon initial inspection or after either stature or weight had been entered into a stepwise multiple regression.

## KEY RESEARCH ACCOMPLISHMENTS:

Analysis of the evaluation of extant equations to predict BSA calculated from laser scans was completed. The reliability of repeated measures, within the same day, on the Vitronic Viro scanner was determined. Linear and nonlinear models to predict BSA from stature and weight were developed from this sample. Attempts to include anthropometric variables other than stature and weight into predictive equations were carried out.

## REPORTABLE OUTCOMES:

Technical reports and journal articles are in preparation.

## CONCLUSIONS:

The Vitronic Viro scanner provides a reliable method of measuring BSA. BSA prediction from currently used equations provides a satisfactory value. Stature and weight are sufficient to predict BSA accurately. Predictions of BSA from stature and weight do not appear to have to be adjusted for gender. Addition or substitution of other anthropometric variables does not appear to improve predictive accuracy.

## REFERENCES:

Boyd E (1935). The growth of the surface area of the human body. Minneapolis MN, University of Minnesota Press

Dubois D, & EF Dubois (1916). Clinical calorimetry. A formula to estimate the approximate surface area is height and weight be known. *Arch Int Med* 17:863-871.

Haycock GB, GJ Schwartz & DH Wisotsky (1978). Geometric method for measuring body surface area: a height-wieght formula validated in infants, children, and adults. *J Pediatr* 93: 62-66

Mitchell D, NB Strydom, CH Van Graan, & WH Van Der Walt (1971). Human surface area: comparison of the Dubois formula with direct photometric measurement. *Pflügers Arch* 325: 188-190.

Moesteller RD (1987). Simplified calculation of body-surface area. *N Eng J Med* 317(17): 1098 (letter).

Tan, K.T., Brandsma, M.G., Daanen, H.A.M. (2001). Body surface area determination using 3D whole body scanners. Proceedings Conference Numerisation 3D, Paris

Tikuisis P, P Meunier & CE Jubenville (2001). Human body surface area: measurement and prediction using three dimensional body scans. *Eur J Appl Physiol* 85: 264-271.

## APPENDICES:

**Appendix A**: Formulae compared in this study.

<u>Boyd</u>:

$$BSA(m^2) = 0.0003207 \times Height(cm)^{0.3} \times Weight(g)^{(0.7285 - 0.0188 \times Log(Weight(g))}$$ (1)

<u>Dubois & Dubois</u>:

$$BSA(cm^2) = 71.84 \times Height^{0.725} \times Weight(kg)^{0.425}$$ (2)

<u>Haycock, Schwartz, & Wisotsky</u>:

$$BSA(cm^2) = 242.65 \times Height(cm)^{0.3964} \times Weight(kg)^{0.5378}$$ (3)

<u>Mitchell et al</u>:

$$BSA(m^2) = 0.208 + 0.945 \times Dubois\ Area(m^2)$$ (4)

<u>Moesteller</u>:

$$BSA(m^2) = \sqrt{\frac{Height(cm) \times Weight(kg)}{3600}}$$ (5)

<u>Tikuisis, Meunier, & Jubenville</u>:

If male: $$BSA(cm^2) = 128.1 \times Height(cm)^{0.60} \times Weight(kg)^{0.44}$$ (6a)

If female: $$BSA(cm^2) = 147.4 \times Height(cm)^{0.55} \times Weight(kg)^{0.47}$$ (6b)